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EFFECT OF AILERON DISPLACEMENT ON WING CHARACTERISTICS

By R. H. Heald  
Bureau of Standards

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## EFFECT OF AILERON DISPLACEMENT ON WING CHARACTERISTICS

By R. H. Heald

## SUMMARY

The effect of aileron displacement on wing characteristics has been investigated for the Clark Y and U.S.A. 27 wing sections equipped with rectangular ailerons. The airfoils, rectangular in plan, and having a 10-inch chord and 60-inch span, were mounted on a model fuselage. Two sets of ailerons, both of 20-inch span, were used, the chord for one set being 2 inches, for the other 3 inches. Measurements were made for angles of pitch of  $0^\circ$ ,  $12^\circ$ ,  $20^\circ$ , and  $40^\circ$ .

When both ailerons were displaced equally in opposite directions (the conventional arrangement), the lift was reduced, the drag increased, and the center of pressure moved forward. When one aileron was displaced downward, the lift was increased, the drag was increased, the center of pressure remained in nearly the same position. When one aileron was displaced upward, the lift was decreased by an amount greater than that observed for the conventional arrangement, the drag was decreased for a large part, although not all, of the range of aileron displacement investigated, and the center of pressure moved forward by an amount not greatly different from that observed for the conventional arrangement.

The one-aileron and two-aileron methods of determining the characteristics of the conventional arrangement were compared and the agreement found to be satisfactory.

The investigations were conducted in the Bureau of Standards 10-foot wind tunnel in cooperation with the Aeronautics Branch of the Department of Commerce and with the National Advisory Committee for Aeronautics.

## INTRODUCTION

The changes in wing characteristics which take place as a result of aileron movement are of importance in connection with the suggested use of one aileron, displaced upward, as a possible means of securing improved lateral control. The effects of the downward displacement of a flap on the lift, drag, and pitching moment of an airfoil have been investigated experimentally by Nayler and others. (References 1 and 2.) The effects of aileron displacement, especially those arising as a result of the upward displacement of a single aileron, or the simultaneous displacement of both ailerons in opposite directions have not been experimentally defined. A theoretical treatment of the subject is given by Wieselsberger in reference 3.

Measurements to determine the effect of aileron displacement are often made using a single aileron. The results for the conventional arrangement, in which ailerons on opposite wings are displaced through equal angles but in opposite directions, are then obtained by computation. This procedure neglects the possible existence of mutual interference when both ailerons are displaced simultaneously. Although an investigation of this effect has been made previously (reference 4), it seemed desirable to conduct the experiments so that a somewhat more detailed comparison could be made of the results obtained by means of the one-aileron and two-aileron methods.

## METHODS OF MEASUREMENT

In order to make the results of this investigation comparable with those given in references 3, 4, and 5, the same fuselage and airfoils were used. The principal dimensions are given in chord lengths in Figure 1a. It will be noted from the figure that the wing is set at an angle of  $+4^\circ$  to the axis of the fuselage and therefore the angle of attack of the wing is always  $4^\circ$  greater than the angle of pitch to which the measurements in this report are referred.

For the determination of lift, drag, and pitching moment the model was suspended in an inverted position at the center of the air stream by means of four small steel wires attached to an adjustable frame above the tunnel.

(Fig. 1b.) The weight of the frame, model, and counterweight  $W_1$  was supported in part by two balances of the pendulum type B and  $B_1$  and, in part, by a counterweight  $W$  acting, by means of a lever, on the horizontal member H of the frame. The connection of this member of the frame to the pitching moment balance B was a point-pulley bearing C. The member H was maintained horizontal during a run by adjusting the screw N according to the indications of a sensitive level mounted on H. Adjustments of the model in pitch were accomplished by tilting the movable member of the frame A, about the axis  $O_2$ . The pitch angles were set off on a scale marked on the sector S, and were checked before and after a run by direct measurement of the distances from the extremities of the fuselage axis to a horizontal reference plane established for the purpose.

In order to stabilize the model with the wing span horizontal, i.e., the condition of zero roll, the movable counterweight  $W_1$  was attached well below it. Small stay wires connected this weight with the wing tips. During a run the counterweight was moved laterally in its fairing a distance sufficient to give a countermoment approximately equal in magnitude to the rolling moment imposed by the aileron displacement. The yawing moments were balanced by the torsional restoring moment of the wire suspension system. The resulting angle of roll was less than  $2^\circ$ , the angle of yaw less than  $1^\circ$ .

When measurements are made using this apparatus the lift of the model is equal to the sum of the net readings indicated by the balances B and  $B_1$ . The drag is determined from the observed deflection due to the wind, the weight  $W_1$  being free to follow this deflection. The total drag is equal to the combined weights of the model, wires, and lower counterweight plus the lift, times the tangent of the angle of deflection. The net drag is equal to the total drag minus the wire drag, which is computed from the diameter and length of the wire and the air speed. The pitching moment about the point of attachment O, of the front wires to the model, referring again to Figure 1b, is determined as follows: The total pitching moment caused by the wind on the model about point O will be equal in magnitude to the total moment about the point  $O_2$ . The experimental apparatus, however, is designed to measure the magnitude of the moment about  $O_1$  instead of  $O_2$ . A correction to the observed moment is accordingly necessary. Since  $O_1$  is located vertically below  $O_2$ ,

that is, in a direction from  $O_2$  parallel to the lift force, and the entire drag force on the model is opposed by a reaction at  $O_1$ , the effect of the correction will be to diminish the observed moment by the value of the total drag times the distance between  $O_1$  and  $O_2$ . The total drag is the sum of the drag of the model and the drag of suspension wires exposed to the air stream. The corrected moment about  $O_1$  is therefore equal to the pitching moment acting about the cross-wind axis through point  $O$  on the model. Lift, drag, and pitching moment observations are made simultaneously. Rolling and yawing moments have been determined previously. (References 3 and 4.)

The 20 by 2 inch and the 20 by 3 inch ailerons mounted on the Clark Y wing and ailerons of the same sizes mounted on the U.S.A. 27 wing were used in this investigation. The observations were made at a wind speed of 40 feet per second corresponding to a Reynolds Number of 210,000.

#### NOTATION

$S$  = wing area (sq.ft.)

$c$  = wing chord (ft.)

$V$  = air speed (ft./sec.)

$$q = \frac{\rho V^2}{2} = 0.001189V^2$$

$L$  = lift (lb.)

$D$  = drag (lb.)

$$C_L = \frac{L}{qS}$$

$$C_D = \frac{D}{qS}$$

$M_o$  = pitching moment about the point of attachment of front wires, -0.

$$C_M = \frac{M_o^*}{q c S}$$

$C_p$  ratio\* to the chord of the distance of the center of pressure from the projection of the leading edge on line A-A, Figures 5-9.

#### COMPARISON OF THE ONE-AILERON AND TWO-AILERON METHODS

In studying the effects of aileron displacement it is often convenient to use a model of half span and a reflecting plane or to use the complete wing with a single aileron. When either of these methods is used, as, for example, in determining rolling and yawing moments, the total moments are obtained by adding, algebraically, the net values for corresponding upward and downward displacements, determined from runs on one aileron. It is assumed that the values so obtained are equal to the values which would be obtained from the simultaneous displacement of both ailerons in opposite directions. Because this method does not take account of mutual interference between the ailerons, its validity has been questioned.

The effect of mutual interference has been investigated previously in the Bureau of Standards 10-foot wind tunnel in connection with the study of rolling and yawing moments and has been found to be of the same order of magnitude as the experimental error, and accordingly negligible in practical performance estimates. As a further check, tests were made on the model (figs. 1a and 1b) in

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\*It is customary and desirable when the model represents a specific airplane to refer the coefficients of pitching moment to a moment center corresponding to the center of gravity of the full-scale airplane and to refer the center of pressure coefficients to the thrust line, which may or may not coincide with the axis of the fuselage. Since the model used in these tests does not represent a specific airplane but rather a general type, it seemed unnecessary to carry through this refinement. The pitching moments with respect to any moment center other than that used, or the center of pressure positions with respect to any fixed point on the fuselage, are readily determinable from the data given either graphically or by computation. The pitching moment coefficients have been included in the tables in order to illustrate the degree of agreement between the one-aileron and two-aileron methods.

connection with the study of the lift, drag, and pitching moment characteristics. The work of the 20 by 2 inch and the 20 by 3 inch ailerons mounted on the Clark Y and U.S.A. 27 wings for 0° pitch was extended to form this part of the investigation. The procedure used in determining the combined values is best described by means of symbols. Let  $L_0$ ,  $D_0$ , and  $M_0$  represent, respectively, the absolute lift, drag, and pitching moment coefficients\* for the model with the ailerons neutral. Let  $\Delta L$ ,  $\Delta D$ , and  $\Delta M$  represent the changes in lift, drag, and pitching moment coefficients when the ailerons are displaced. Also let the subscripts  $r$  and  $l$  represent the right and left ailerons, respectively, and the subscripts  $u$  and  $d$  represent the direction of the displacements, upward and downward, respectively.

The changes in the coefficients for the model when the ailerons are displaced are represented by

$\Delta L_{ru}$ ,  $\Delta D_{ru}$  and  $\Delta M_{ru}$  when the right aileron is displaced upward,

$\Delta L_{lu}$ ,  $\Delta D_{lu}$  and  $\Delta M_{lu}$  when the left aileron is displaced upward,

$\Delta L_{rd}$ ,  $\Delta D_{rd}$  and  $\Delta M_{rd}$  when the right aileron is displaced downward,

and

$\Delta L_{ld}$ ,  $\Delta D_{ld}$  and  $\Delta M_{ld}$  when the left aileron is displaced downward.

The mean changes in  $L$ ,  $D$ , and  $M$  are:

$$\Delta L_u = \frac{(L_0 - L_{ru}) + (L_0 - L_{lu})}{2}; \quad \Delta L_d = \frac{(L_0 - L_{rd}) + (L_0 - L_{ld})}{2}$$

$$\Delta D_u = \frac{(D_0 - D_{ru}) + (D_0 - D_{lu})}{2}; \quad \Delta D_d = \frac{(D_0 - D_{rd}) + (D_0 - D_{ld})}{2}$$

$$\Delta M_u = \frac{(M_0 - M_{ru}) + (M_0 - M_{lu})}{2}; \quad \Delta M_d = \frac{(M_0 - M_{rd}) + (M_0 - M_{ld})}{2}$$

The values for the lift, drag, and moment coefficients given in the tables, for 0° pitch labeled "up and down, by

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\*These designations are used for the coefficients to avoid awkward double subscripts.

addition" are obtained from the expressions:

$$C_L = L_0 + \Delta L_u + \Delta L_d$$

$$C_D = D_0 + \Delta D_u + \Delta D_d$$

$$C_M = M_0 + \Delta M_u + \Delta M_d$$

The values for  $0^\circ$  pitch labeled "up and down, by observation" are obtained from the expressions:

$$C_L = \frac{L_{ruld} + L_{lurd}}{2}$$

$$C_D = \frac{D_{ruld} + D_{lurd}}{2}$$

$$C_M = \frac{M_{ruld} + M_{lurd}}{2}$$

Because of the general unsteadiness of the model at the high pitch angles, measurements were made only on the right aileron in the one-aileron method. The values in Tables I-IV headed "up and down, by addition" for pitch angles of  $12^\circ$ ,  $20^\circ$ , and  $40^\circ$  were determined from the following expressions:

$$C_L = L_0 + \Delta L_{ru} + \Delta L_{rd}$$

$$C_D = D_0 + \Delta D_{ru} + \Delta D_{rd}$$

$$C_M = M_0 + \Delta M_{ru} + \Delta M_{rd}$$

The values in the columns headed "up and down, by observation" for pitch angles of  $12^\circ$ ,  $20^\circ$ , and  $40^\circ$  were obtained from observations made using both ailerons, displaced simultaneously in opposite directions, the right aileron up, the left one down. This method necessarily lacks the precision of the one adopted for  $0^\circ$  pitch in that the angles of attack at the wing tips may differ because of warping of the model or unsymmetrical air flow in the tunnel.

It will be seen from the tables that in general the observed and computed values of the lift and drag coefficients agree within a few per cent for all pitch settings.



In some cases the observed and computed pitching moment coefficients differ decidedly when the aileron displacement is greater than  $24^\circ$ . This appears to be due to the combined effects of difference in angle of attack of the wing at the tips, air spin in the tunnel, and unsteady air flow about the model, particularly at high aileron angles.

#### EFFECT OF AILERON DISPLACEMENT ON WING CHARACTERISTICS

The results of this part of the investigation are given numerically in Tables I-IV. Figures 2 to 9 illustrate graphically the changes in lift, drag, and center of pressure in the case of the Clark Y wing. The results show the effects of aileron displacement to be similar for both the Clark Y and U.S.A. 27 wings.

In general, the changes in lift coefficient (fig. 2) are approximately proportional to aileron displacement. In most cases the loss in lift of the wing due to a given upward displacement of one aileron is somewhat greater than the gain in lift due to an equal downward displacement, in agreement with the relationship existing between the corresponding rolling moments, noted in references 3 and 4. The total lift of the wing is therefore decreased slightly when the ailerons are displaced equally and simultaneously, one up, the other down. (Fig. 2.) The marked change in the slope of the curve of lift coefficient against aileron angle (fig. 2) which occurs above the  $24^\circ$  point, is in substantial agreement with the change in slope of the rolling moment curve for the same conditions.

The upward displacement of one aileron causes a decrease in total drag through a large range of aileron travel, as illustrated in Figure 3. In the case of the 20 by 2 inch aileron on the Clark Y wing,  $0^\circ$  pitch (fig. 3), the total drag as compared with the drag when the aileron is neutral, is reduced throughout the range of aileron travel between  $0^\circ$  and  $23^\circ$ . The maximum reduction, 13 per cent, occurs when the displacement is  $11^\circ$ . When the pitch angle is increased to  $12^\circ$  the region of reduced drag extends beyond the  $44^\circ$  aileron displacement. The maximum reduction in drag coefficient for a pitch angle of  $12^\circ$  is 15 per cent and occurs when the aileron is displaced  $22^\circ$ . The change in direction of the drag increment due to the upward displacement of one aileron is in

agreement with the reversal in direction of the yawing moment. Simultaneous displacement of both ailerons, equally but in opposite directions, results in increasing the drag of the model for all conditions investigated.

The center of pressure positions were computed using the observed values of lift, drag, and pitching moment. Upward displacement of one aileron causes the center of pressure of the model to move forward. The amount of movement depends on the amount of upward aileron displacement and on the pitch angle of the model as illustrated in Figures 4-9. Reference to Figure 4 and to the tables will show that the amount of center of pressure movement is also governed by the aileron chord, being definitely greater for displacements of more than  $24^\circ$  in the case of the larger ailerons. When both large chord ailerons are displaced equally but in opposite directions, the pitch angle being  $0^\circ$ , the center of pressure moves less than when one large chord aileron is displaced upward. The travel of the center of pressure on the model due to aileron displacement is relatively greater than the travel due to changing the angle of pitch within the range of these tests. Referring to Table I, for example, displacing both ailerons  $24^\circ$  with  $0^\circ$  pitch angle reduces the value of the center of pressure coefficient from 0.34 to 0.28, while increasing the pitch from  $0^\circ$  to  $20^\circ$  with ailerons neutral reduces the value of  $C_p$  from 0.34 to 0.32.

### CONCLUSION

A comparison of the results obtained by the one-aileron and the two-aileron methods of estimating the performance of the conventional arrangement indicates that neglecting mutual interference between the ailerons is not an important factor affecting the precision of the results. The most disturbing factors appear to arise from (1) difference in the angle of attack of the wing at the tips and at midspan due to warping or to wind loading during a run and (2) spin in the tunnel air stream.

The effects of the upward displacement of one aileron determined as a result of this investigation are:

1. A reduction in total lift, the amount of the reduction depending on the chord of the aileron and the displacement.

2. A reduction in total drag at least until the aileron displacement becomes very large.

3. A forward travel of the center of pressure of the model. In general, this travel is comparable with or a little greater than the travel due to the displacement of both ailerons in the conventional manner.

Bureau of Standards,

Washington, D. C., October 13, 1932.

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TABLE I. CHARACTERISTICS OF CLARK Y AIRFOIL AND FUSELAGE, WITH 20 BY 2 INCH AILERONS

$\theta$	$\delta_A$	Lift coefficient				Drag coefficient				Moment coefficient				$C_p$		
		Up	Down	Up and down (by addition)	Up and down (by observation)	Up	Down	Up and down (by addition)	Up and down (by observation)	Up	Down	Up and down (by addition)	Up and down (by observation)	Up	Down	Up and down (by observation)
0°	0°	0.71	0.71	0.71	0.71	0.053	0.053	0.053	0.053	0.67	0.67	0.67	0.67	0.34	0.34	0.34
	4°	.67	.76	.72	.71	.050	.059	.056	.054	.62	.72	.67	.66	.32	.35	.33
	8°	.61	.82	.72	.70	.047	.066	.059	.059	.56	.77	.66	.65	.31	.34	.33
	16°	.53	.90	.72	.69	.048	.078	.073	.070	.45	.85	.63	.62	.28	.34	.29
	24°	.49	.92	.70	.67	.054	.089	.090	.080	.43	.86	.62	.59	.27	.33	.28
	32°	.42	.97	.68	.66	.081	.105	.113	.111	.35	.89	.57	.58	.24	.32	.24
	40°	.38	1.00	.65	.64	.070	.118	.135	.133	.28	.91	.52	.52	.19	.31	.21
	44°	.35	1.00	.64	.62	.076	.123	.146	.145	.28	.91	.50	.48	.15	.31	.17
12°	0°	1.11	1.11	1.11	1.11	0.20	0.20	0.20	0.20	1.06	1.06	1.06	1.03	0.34	0.34	0.34
	4°	1.11	1.11	1.11	1.09	.20	.21	.21	.20	1.05	1.07	1.06	1.03	.33	.35	.33
	8°	1.08	1.11	1.08	1.11	.19	.22	.21	.21	1.02	1.06	1.02	1.03	.34	.34	.32
	16°	1.03	1.12	1.04	1.07	.18	.24	.21	.21	.95	1.07	0.97	.99	.31	.34	.30
	24°	1.01	1.13	1.03	1.05	.17	.25	.22	.21	.92	1.10	.96	.96	.30	.35	.30
	32°	1.02	1.14	1.05	1.08	.18	.27	.25	.24	.92	1.10	.96	.98	.29	.34	.29
	40°	1.01	1.16	1.06	1.07	.18	.23	.26	.26	.91	1.12	.97	.97	.29	.34	.28
	44°	0.98	1.16	1.03	1.07	.18	.28	.26	.27	.87	1.12	.93	.95	.28	.34	.25
20°	0°	0.92	0.92	0.92	0.92	0.48	0.48	0.48	0.48	0.95	0.95	0.95	0.95	0.32	0.32	0.32
	4°	.92	.92	.92	.92	.47	.49	.48	.49	.95	.95	.95	.95	.32	.32	.32
	8°	.90	.92	.90	.89	.46	.50	.48	.48	.95	.95	.95	.91	.34	.33	.28
	16°	.87	.92	.87	.89	.45	.51	.48	.49	.88	.95	.87	.91	.30	.35	.28
	24°	.84	.95	.87	.88	.44	.55	.52	.50	.83	.97	.85	.86	.29	.37	.21
	32°	.84	.97	.89	.86	.45	.58	.55	.52	.83	1.00	.88	.88	.28	.36	.19
	40°	.85	.97	.90	.86	.45	.58	.58	.54	.83	1.00	.88	.85	.27	.35	.17
	44°	.85	.97	.90	.88	.47	.58	.57	.55	.83	1.00	.88	.85	.27	.35	.17
40°	0°	0.87	0.87	0.87	0.87	0.92	0.92	0.92	0.92	1.19	1.19	1.19	1.19	0.34	0.34	0.34
	4°	.86	.86	.85	.86	.91	.91	.91	.91	1.15	1.19	1.15	1.16	.32	.35	.33
	8°	.84	.86	.83	.85	.90	.92	.90	.90	1.12	1.19	1.12	1.14	.32	.35	.33
	16°	.82	.88	.83	.84	.87	.95	.90	.91	1.09	1.21	1.10	1.16	.31	.34	.32
	24°	.80	.87	.80	.84	.85	.96	.89	.91	1.06	1.19	1.06	1.16	.31	.32	.33
	32°	.78	.88	.79	.82	.84	.98	.88	.91	1.01	1.20	1.02	1.09	.29	.33	.26
	40°	.78	.90	.81	.82	.84	1.00	.92	.94	1.03	1.21	1.05	1.11	.31	.32	.26
	44°	.80	.90	.83	.85	.85	1.01	.94	.96	1.07	1.24	1.12	1.16	.33	.33	.29

TABLE II. CHARACTERISTICS OF CLARK Y AIRFOIL AND FUSELAGE, WITH 20 BY 3 INCH AILERONS

$\theta$	$\delta_A$	Lift coefficient				Drag coefficient				Moment coefficient				$C_p$		
		Up	Down	Up and down (by addition)	Up and down (by observation)	Up	Down	Up and down (by addition)	Up and down (by observation)	Up	Down	Up and down (by addition)	Up and down (by observation)	Up	Down	Up and down (by observation)
0°	0°	0.71	0.71	0.71	0.71	0.053	0.053	0.053	0.053	0.67	0.67	0.67	0.67	0.34	0.34	0.34
	4°	.63	.76	.69	.69	.048	.059	.054	.053	.59	.73	.65	.65	.34	.36	.34
	8°	.58	.81	.68	.67	.045	.066	.058	.058	.54	.78	.65	.64	.33	.35	.35
	16°	.48	.89	.66	.64	.048	.084	.079	.077	.42	.85	.62	.58	.27	.34	.31
	24°	.42	.95	.65	.62	.059	.099	.105	.104	.35	.90	.58	.53	.21	.37	.25
	32°	.35	.96	.59	.59	.072	.118	.137	.137	.27	.90	.50	.47	.16	.32	.19
	40°	.29	1.00	.58	.55	.088	.137	.172	.172	.18	.92	.43	.39	.01	.32	.11
	44°	.26	1.02	.57	.55	.095	.150	.192	.189	.15	.94	.42	.37	.02	.34	.06
12°	0°	1.11	1.11	1.11	1.11	0.20	0.20	0.20	0.20	1.06	1.06	1.06	1.06	0.34	0.34	0.34
	4°	1.10	1.13	1.12	1.12	.19	.21	.20	.20	1.05	1.09	1.07	1.06	.34	.34	.33
	8°	1.07	1.12	1.08	1.10	.18	.22	.20	.20	1.01	1.08	1.03	1.03	.33	.35	.33
	16°	1.01	1.14	1.04	1.03	.16	.25	.21	.20	0.90	1.08	0.92	0.92	.28	.33	.28
	24°	.93	1.15	0.97	0.99	.15	.26	.21	.20	.78	1.10	.82	.88	.23	.33	.28
	32°	.88	1.16	.93	.96	.16	.28	.24	.23	.74	1.11	.79	.82	.23	.33	.23
	40°	.88	1.18	.95	.94	.17	.22	.29	.27	.72	1.12	.78	.76	.20	.32	.17
	44°	.81	1.19	.89	.91	.17	.24	.30	.28	.64	1.14	.72	.73	.18	.32	.17
20°	0°	0.92	0.92	0.92	0.92	0.48	0.48	0.48	0.48	0.95	0.95	0.95	0.95	0.32	0.32	0.32
	4°	.90	.92	.90	.92	.47	.50	.49	.49	.91	.99	.95	.95	.30	.35	.34
	8°	.88	.92	.88	.92	.46	.50	.48	.50	.87	.97	.90	.93	.29	.34	.30
	16°	.85	.92	.85	.90	.44	.54	.50	.50	.85	1.00	.90	.90	.29	.35	.28
	24°	.83	.96	.87	.87	.43	.58	.51	.50	.81	1.00	.86	.85	.24	.31	.26
	32°	.84	.96	.86	.86	.42	.58	.52	.53	.81	1.00	.86	.80	.26	.31	.21
	40°	.83	.96	.87	.86	.43	.60	.55	.55	.80	1.01	.83	.80	.26	.29	.20
	44°	.82	.96	.86	.86	.44	.61	.57	.56	.77	.99	.81	.80	.24	.29	.20
40°	0°	0.87	0.87	0.87	0.87	0.92	0.92	0.92	0.92	1.19	1.19	1.19	1.19	0.34	0.34	0.34
	4°	.89	.91	.93	.88	.94	.93	.97	.91	1.22	1.27	1.31	1.19	.27	.38	.34
	8°	.90	.92	.95	.88	.96	.95	.99	.93	1.24	1.29	1.34	1.19	.34	.38	.33
	16°	.88	.94	.95	.87	.91	.98	.95	.93	1.20	1.30	1.31	1.15	.35	.38	.31
	24°	.85	.93	.91	.86	.88	.99	.95	.94	1.14	1.29	1.24	1.12	.34	.36	.29
	32°	.80	.92	.85	.85	.86	1.01	.95	.93	1.06	1.26	1.16	1.09	.31	.35	.27
	40°	.79	.92	.84	.80	.86	1.02	.96	.91	1.05	1.26	1.12	1.07	.31	.33	.24
	44°	.82	.91	.88	.82	.86	1.03	.97	.92	1.10	1.25	1.16	1.05	.33	.32	.26

TABLE III. CHARACTERISTICS OF U.S.A. 27 AIRFOIL AND FUSELAGE, WITH 20 BY 2 INCH AILERONS

$\theta$	$\delta_A$	Lift coefficient				Drag coefficient				Moment coefficient				$C_p$		
		Up	Down	Up and down (by addi- tion)	Up and down (by obser- vation)	Up	Down	Up and down (by addi- tion)	Up and down (by obser- vation)	Up	Down	Up and down (by addi- tion)	Up and down (by obser- vation)	Up	Down	Up and down (by obser- vation)
0°	0°	0.68	0.68	0.68	0.68	0.043	0.043	0.043	0.043	0.62	0.62	0.62	0.62	0.31	0.31	0.31
	4°	.59	.72	.63	.85	.035	.048	.038	.041	.53	.66	.58	.58	.28	.31	.29
	8°	.53	.76	.60	.84	.034	.050	.041	.046	.48	.72	.58	.57	.30	.35	.29
	16°	.50	.82	.64	.82	.037	.061	.058	.056	.44	.78	.56	.53	.28	.35	.28
	24°	.48	.84	.64	.81	.041	.069	.067	.072	.42	.80	.60	.53	.27	.35	.27
	32°	.33	.90	.65	.58	.050	.088	.093	.091	.34	.84	.56	.44	.29	.33	.18
	40°	.37	.93	.62	.57	.058	.098	.101	.107	.27	.86	.51	.41	.21	.32	.12
12°	0°	1.20	1.20	1.20	1.20	0.17	0.17	0.17	0.17	1.15	1.15	1.15	1.15	0.35	0.35	0.35
	4°	1.19	1.21	1.20	1.19	.16	.18	.17	.17	1.15	1.18	1.16	1.14	.36	.35	.35
	8°	1.18	1.23	1.21	1.20	.15	.19	.17	.17	1.15	1.19	1.19	1.15	.37	.35	.35
	16°	1.15	1.28	1.21	1.18	.14	.20	.17	.17	1.09	1.21	1.15	1.11	.34	.35	.33
	24°	1.13	1.28	1.21	1.17	.14	.22	.19	.19	1.06	1.24	1.15	1.07	.34	.35	.30
	32°	1.11	1.28	1.19	1.17	.15	.23	.20	.20	1.03	1.25	1.13	1.09	.33	.36	.31
	40°	1.09	1.28	1.17	1.16	.15	.24	.21	.21	1.01	1.24	1.10	1.05	.32	.35	.30
20°	0°	1.02	1.02	1.02	1.02	0.38	0.38	0.38	0.38	1.06	1.06	1.06	1.06	0.37	0.37	0.37
	4°	0.99	1.03	1.00	1.03	.35	.39	.36	.38	1.05	1.08	1.05	1.09	.39	.37	.39
	8°	.89	1.04	1.01	1.04	.34	.39	.35	.37	1.04	1.07	1.05	1.10	.39	.37	.39
	16°	.88	1.08	1.04	1.04	.33	.41	.38	.39	1.02	1.12	1.08	1.07	.39	.37	.37
	24°	.85	1.08	1.01	1.03	.32	.45	.39	.41	0.97	1.10	1.01	1.04	.37	.34	.34
	32°	.97	1.08	1.03	1.03	.33	.47	.42	.46	1.00	1.11	1.05	1.05	.38	.34	.33
	40°	.95	1.12	1.05	1.02	.35	.47	.44	.47	0.99	1.14	1.07	1.02	.37	.34	.31
40°	0°	0.90	0.90	0.90	0.90	0.68	0.68	0.68	0.68	1.23	1.23	1.23	1.23	0.38	0.38	0.38
	4°	.90	.91	.91	.92	.69	.69	.69	.69	1.20	1.25	1.23	1.25	.36	.39	.38
	8°	.90	.92	.92	.92	.68	.90	.90	.90	1.20	1.26	1.24	1.24	.36	.38	.37
	16°	.89	.93	.92	.92	.67	.90	.89	.90	1.19	1.27	1.24	1.24	.36	.39	.36
	24°	.85	.95	.90	.89	.65	.94	.91	.94	1.14	1.31	1.23	1.19	.35	.39	.34
	32°	.82	.94	.86	.86	.63	.94	.89	.94	1.09	1.29	1.16	1.14	.34	.37	.33
	40°	.85	.96	.91	.88	.66	.97	.95	.97	1.12	1.31	1.21	1.17	.33	.37	.32
44°	0°	.87	.96	.93	.88	.66	.97	.95	.97	1.15	1.31	1.24	1.19	.34	.37	.35

TABLE IV. CHARACTERISTICS OF U.S.A. 27 AIRFOIL AND FUSELAGE, WITH 20 BY 3 INCH AILERONS

$\theta$	$\delta_A$	Lift coefficient				Drag coefficient				Moment coefficient				$C_p$		
		Up	Down	Up and down (by addi- tion)	Up and down (by obser- vation)	Up	Down	Up and down (by addi- tion)	Up and down (by obser- vation)	Up	Down	Up and down (by addi- tion)	Up and down (by obser- vation)	Up	Down	Up and down (by obser- vation)
0°	0°	0.68	0.68	0.68	0.68	0.043	0.043	0.043	0.043	0.62	0.62	0.62	0.62	0.31	0.31	0.31
	4°	.61	.73	.68	.87	.039	.048	.044	.045	.54	.66	.58	.59	.29	.32	.28
	8°	.54	.77	.63	.85	.034	.053	.044	.050	.47	.71	.56	.58	.28	.33	.28
	16°	.44	.82	.57	.88	.041	.069	.065	.066	.37	.74	.49	.49	.24	.30	.25
	24°	.40	.87	.58	.87	.049	.088	.084	.096	.33	.78	.49	.45	.22	.32	.20
	32°	.35	.90	.57	.88	.065	.106	.128	.128	.28	.81	.45	.44	.14	.30	.15
	40°	.39	.93	.54	.86	.078	.121	.153	.158	.19	.81	.38	.40	.05	.27	.09
12°	0°	1.20	1.20	1.20	1.20	0.17	0.17	0.17	0.17	1.15	1.15	1.15	1.15	0.35	0.35	0.35
	4°	1.19	1.24	1.23	1.18	.16	.18	.17	.17	1.14	1.19	1.18	1.15	.35	.35	.36
	8°	1.14	1.24	1.18	1.19	.14	.20	.17	.17	1.07	1.20	1.13	1.11	.34	.36	.33
	16°	1.07	1.23	1.10	1.12	.13	.22	.13	.18	1.00	1.19	1.04	1.03	.33	.35	.31
	24°	1.00	1.25	1.05	1.04	.12	.23	.19	.18	0.90	1.20	0.95	0.92	.30	.34	.27
	32°	0.99	1.24	1.03	1.05	.13	.25	.21	.22	.87	1.19	.91	.91	.28	.35	.24
	40°	.98	1.26	1.02	1.01	.14	.27	.24	.24	.85	1.19	.89	.86	.27	.32	.23
20°	0°	1.02	1.02	1.02	1.02	0.38	0.38	0.38	0.38	1.06	1.06	1.06	1.06	0.37	0.37	0.37
	4°	1.00	1.04	1.02	1.02	.38	.39	.39	.38	1.03	1.08	1.06	1.08	.37	.38	.38
	8°	1.00	1.06	1.04	1.03	.36	.42	.40	.40	1.02	1.11	1.07	1.06	.36	.38	.36
	16°	.96	1.08	1.02	1.04	.35	.44	.41	.41	0.97	1.14	1.05	1.06	.35	.37	.35
	24°	.91	1.08	0.97	0.97	.31	.47	.40	.42	.90	1.14	0.98	0.97	.34	.36	.32
	32°	.88	1.07	0.93	.94	.31	.49	.42	.45	.87	1.14	.95	.91	.33	.37	.28
	40°	.93	1.09	1.00	.96	.32	.52	.46	.48	.90	1.14	.98	.92	.32	.34	.27
40°	0°	0.90	0.90	0.90	0.90	0.68	0.68	0.68	0.68	1.23	1.23	1.23	1.23	0.38	0.38	0.38
	4°	.90	.90	.90	.91	.67	.92	.92	.89	1.23	1.21	1.21	1.24	.38	.35	.38
	8°	.88	.92	.90	.90	.64	.92	.92	.89	1.20	1.25	1.23	1.23	.39	.36	.37
	16°	.86	.95	.91	.88	.67	.96	.95	.90	1.15	1.30	1.23	1.20	.35	.37	.36
	24°	.83	.93	.86	.87	.63	.97	.92	.90	1.10	1.29	1.17	1.16	.34	.36	.34
	32°	.81	.92	.83	.82	.61	.96	.91	.90	1.06	1.30	1.14	1.08	.33	.37	.30
	40°	.77	.91	.78	.77	.61	.99	.92	.88	1.02	1.25	1.05	1.02	.32	.34	.29
44°	0°	.82	.91	.83	.84	.63	1.00	.95	.84	1.08	1.24	1.10	1.00	.34	.32	.29



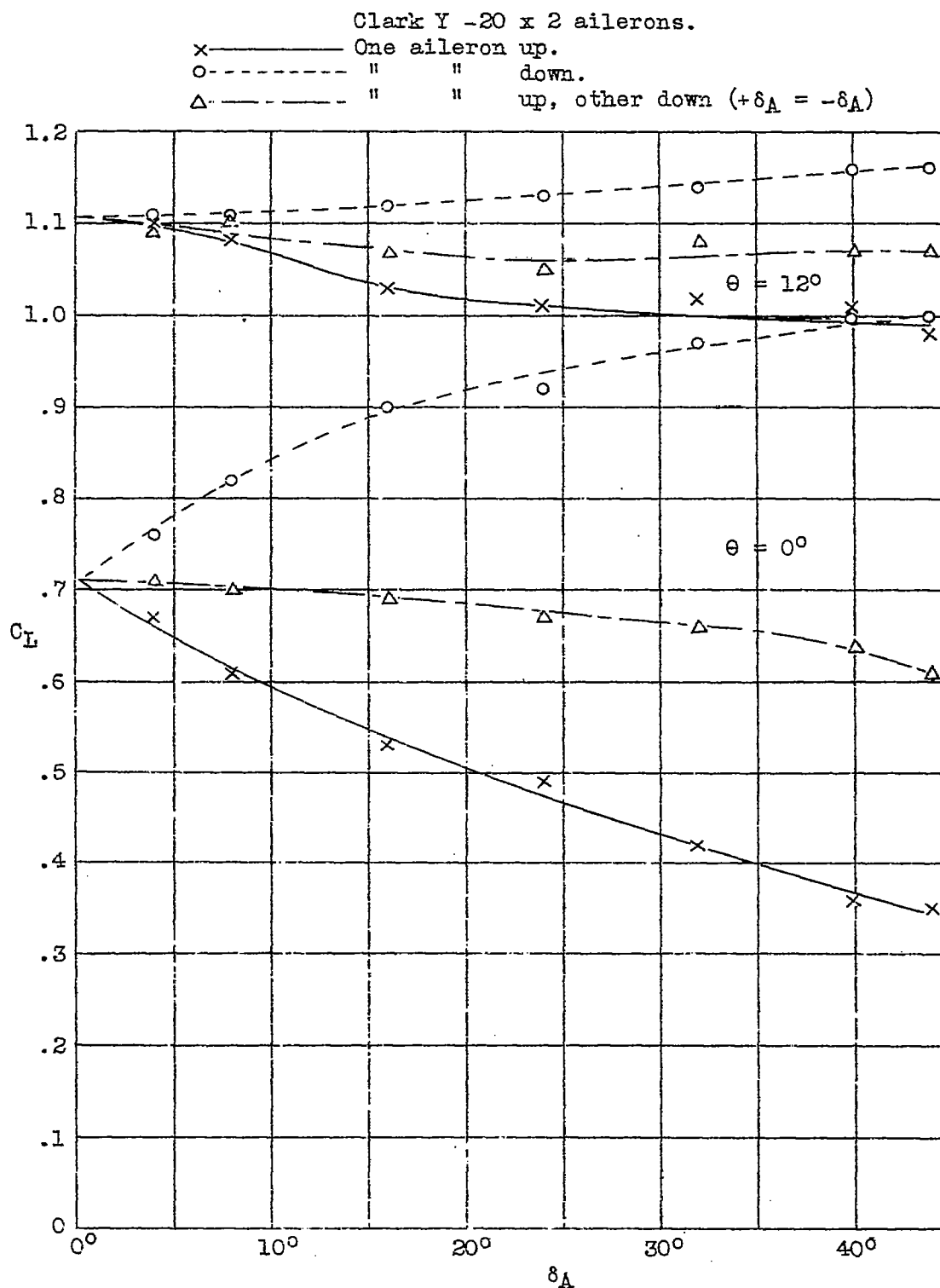
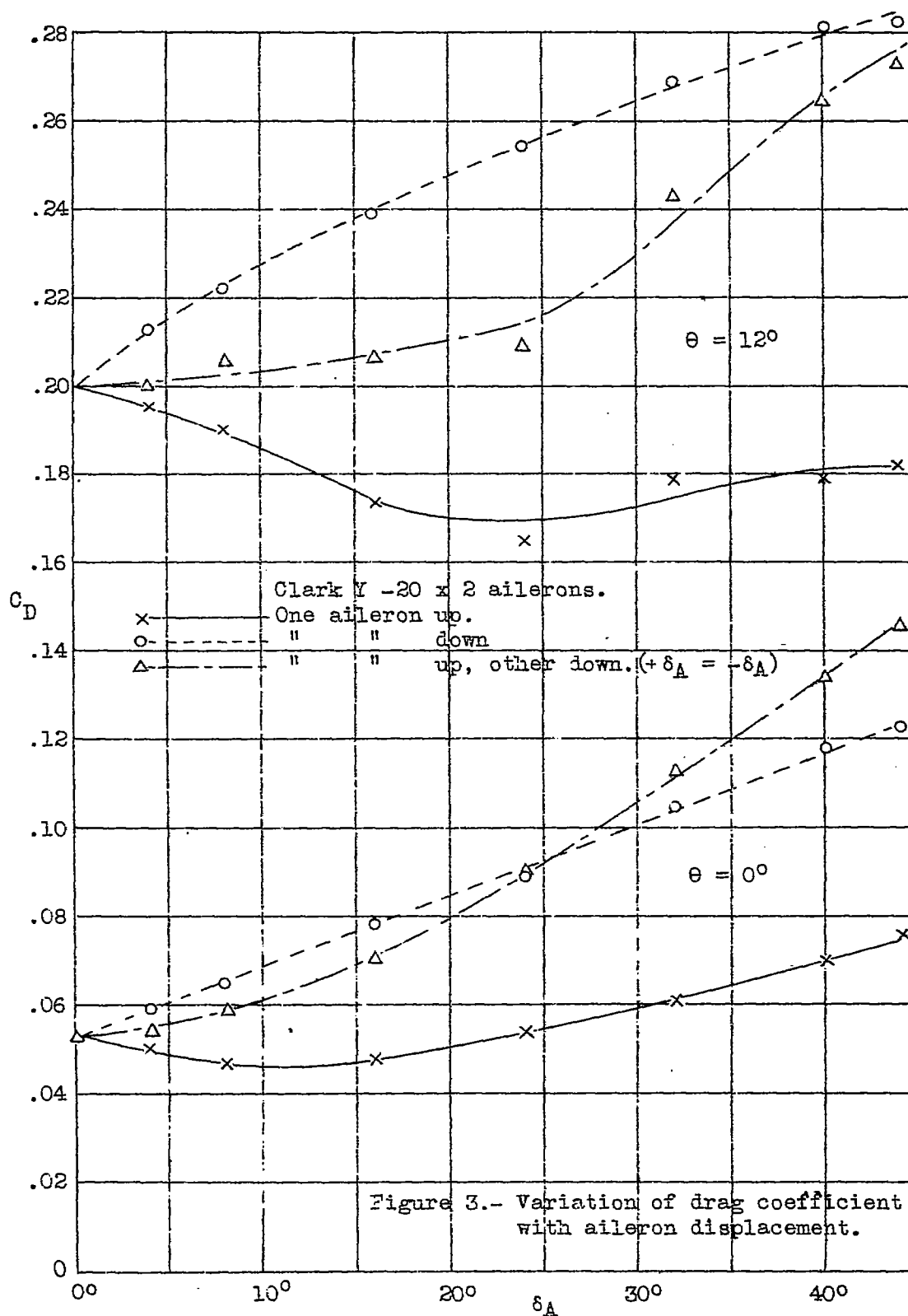


Figure 2.- Variation of lift coefficient with aileron displacement.





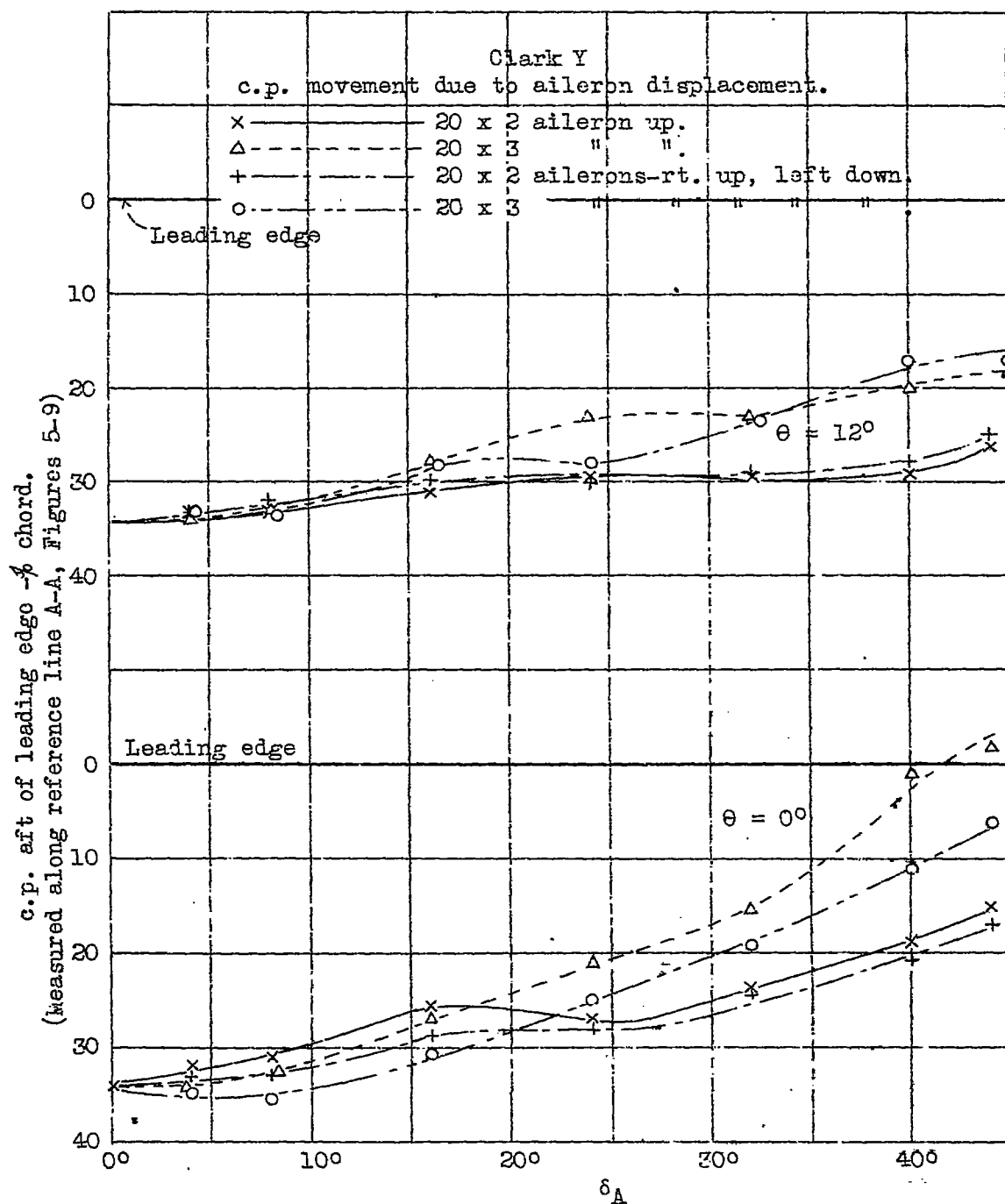


Figure 4.- Typical center of pressure curves.

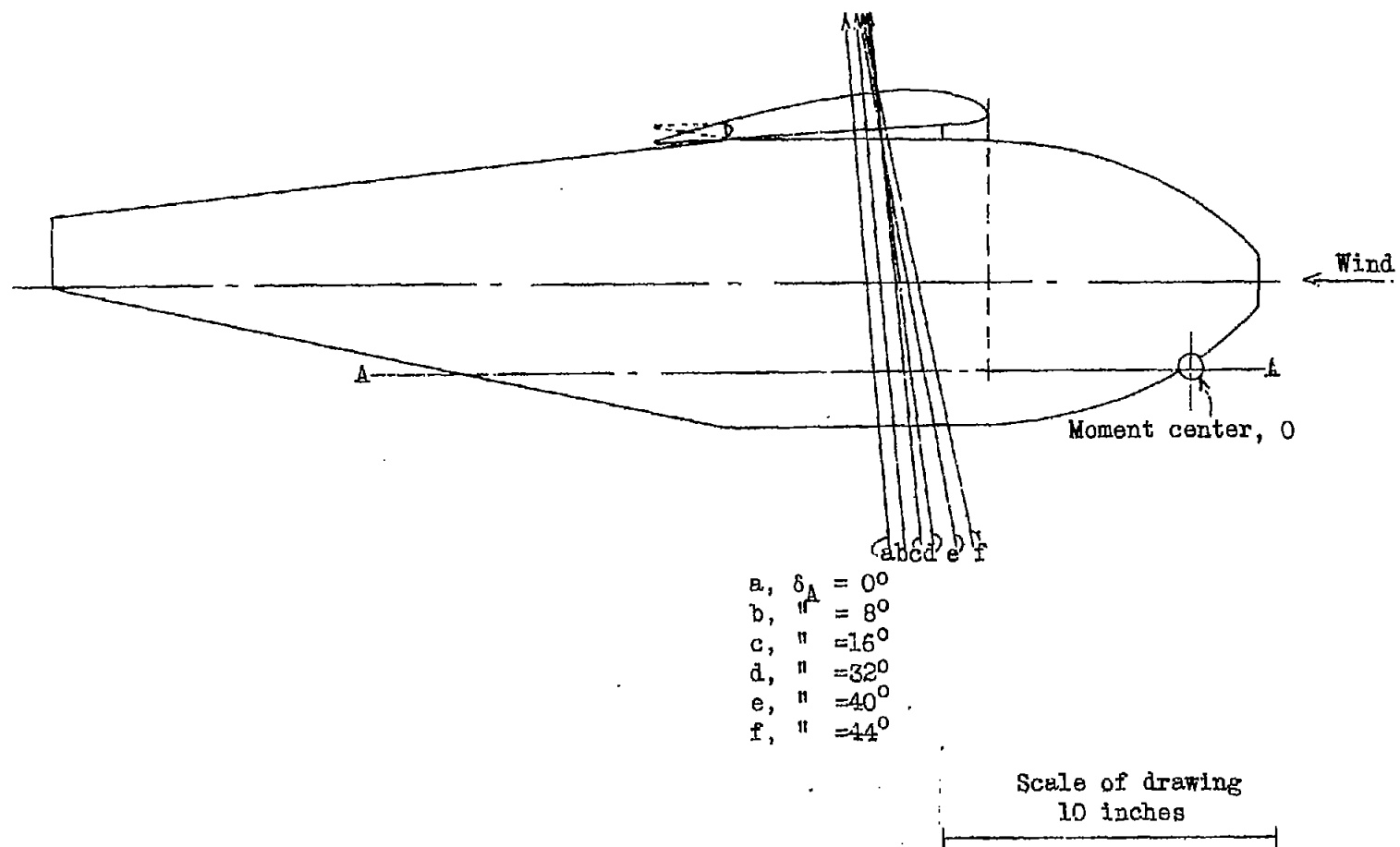


Figure 5.-Vector diagram, 20 by 2 inch aileron up.  $\theta = 0^\circ$ . Clark Y airfoil.

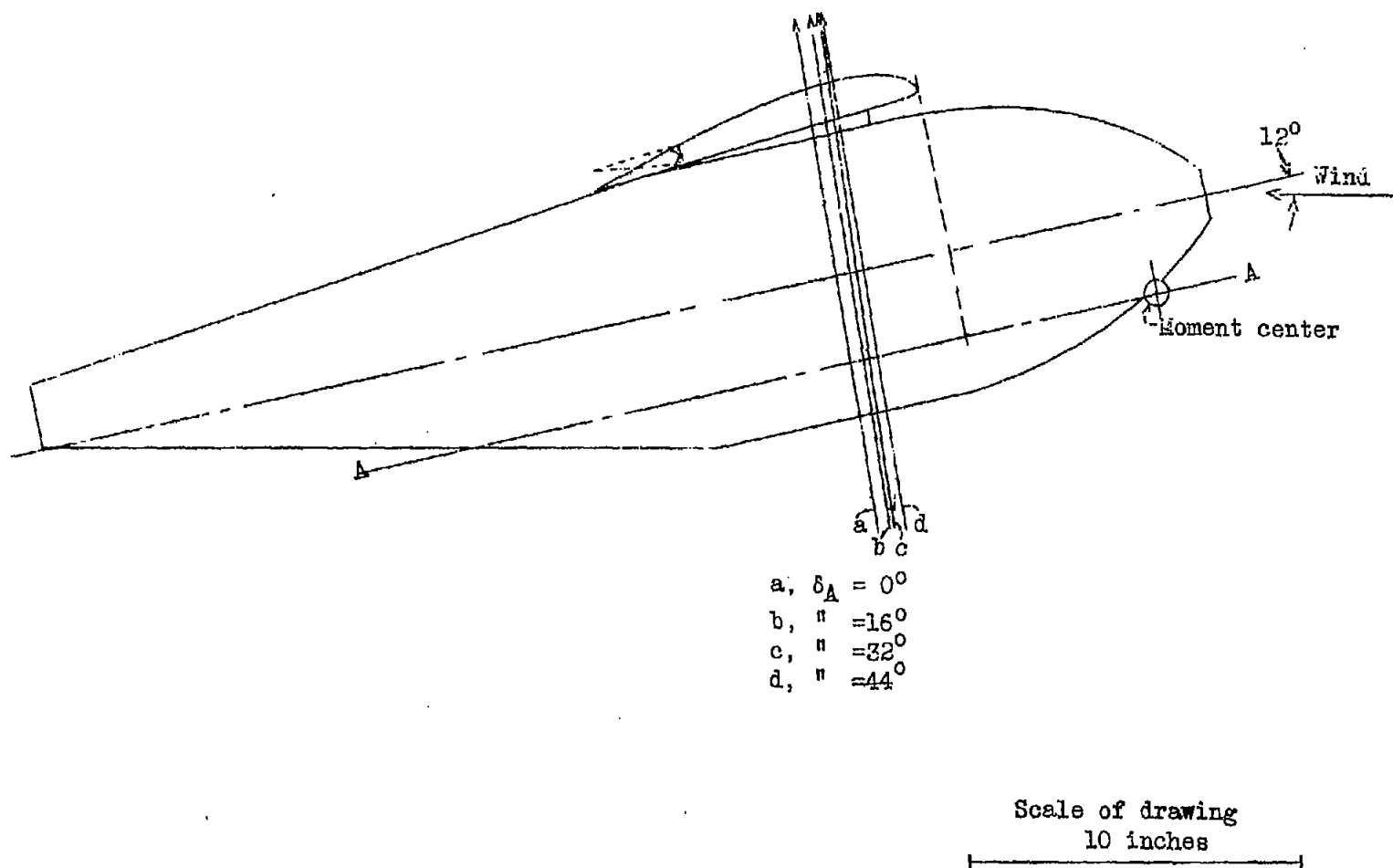


Figure 6.-Vector diagram, 20 by 2 inch aileron up.  $\theta = 12^\circ$ . Clark Y airfoil.

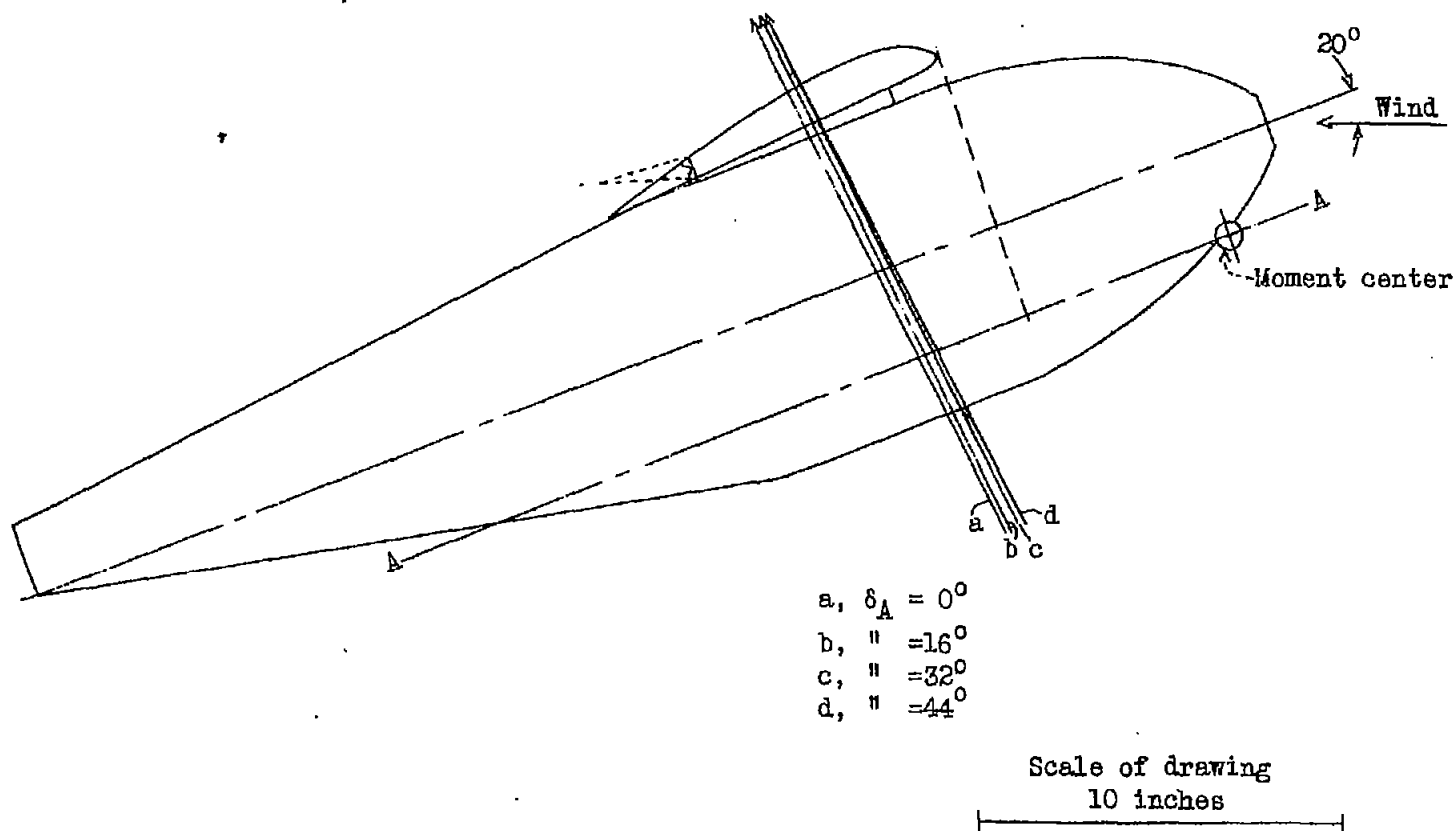


Figure 7.—Vector diagram, 20 by 2 inch aileron up.  $\theta = 20^\circ$ . Clark Y airfoil.

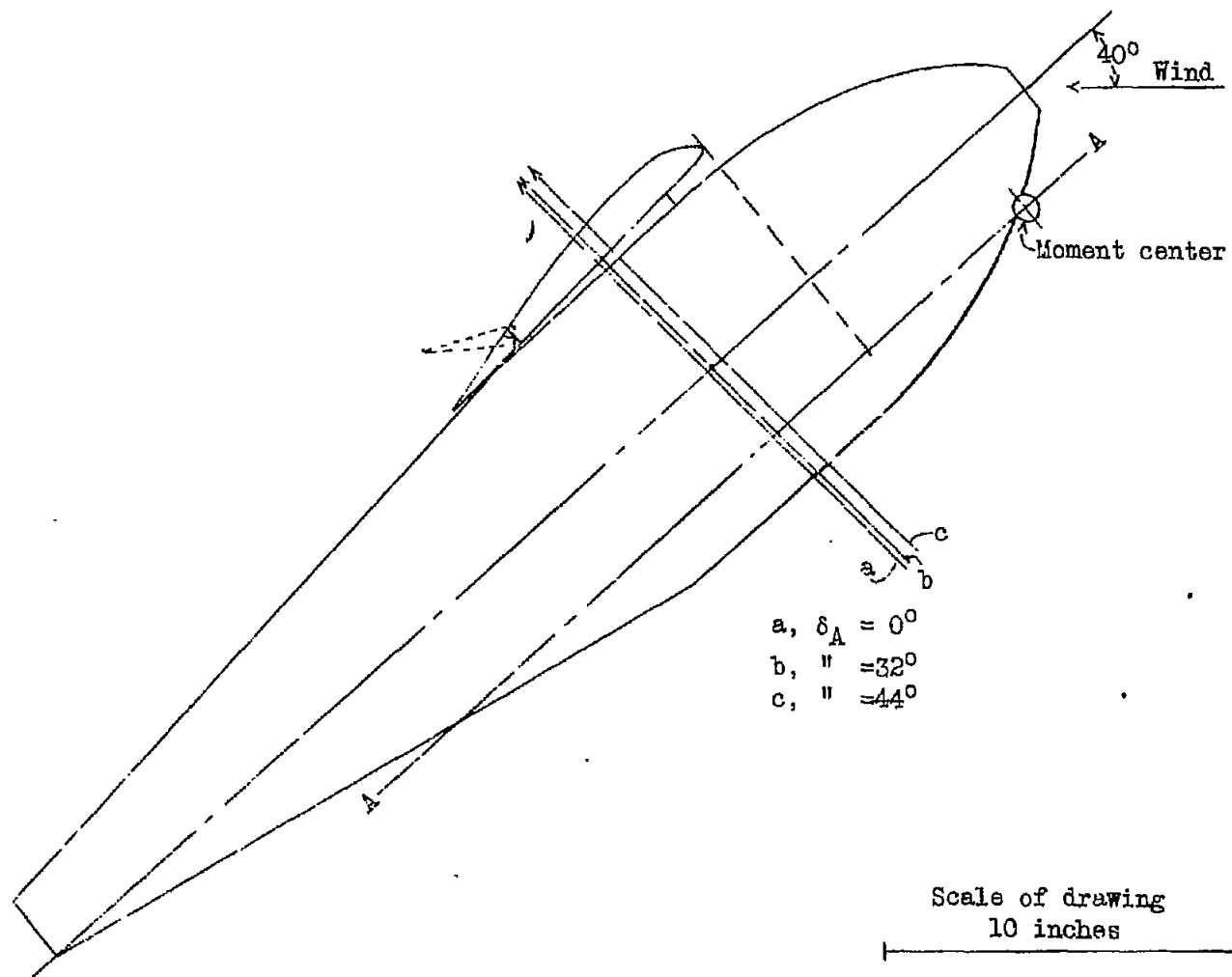


Figure 8.-Vector diagram, 30 by 2 inch aileron up.  $\theta = 40^\circ$ . Clark Y airfoil.

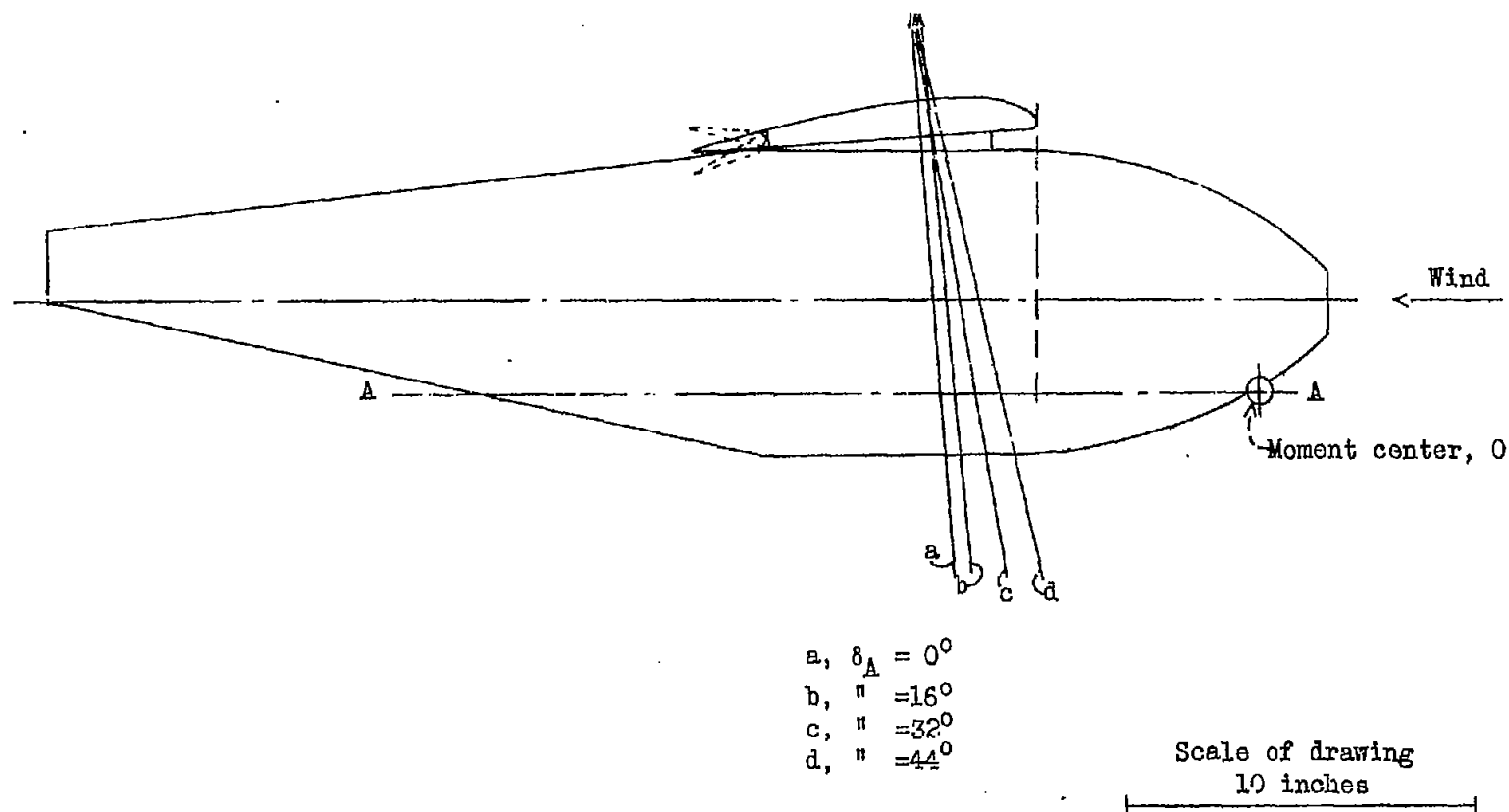


Figure 9.—Vector diagram, 20 by 2 inch aileron, right up, left down.  $\theta = 0^\circ$ . Clark Y airfoil.